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A Sketch-Based Interface for Annotation of 3D Brain Vascular Reconstructions

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Abstract Within the medical imaging community, 3D models of anatomical structures are now widely used in order to establish more accurate diagnoses than those based on 2D images. Many research works focus on an automatic process to build such 3D models. However automatic reconstruction induces many artifacts if the anatomical structure exhibits tortuous and thin parts (such as vascular networks) and the correction of these artifacts involves 3D-modeling skills and times that radiologists do not have. This article presents a semi-automatic approach to build a correct topology of vascular networks from 3D medical images. The user interface is based on sketching; user strokes both defines a command and the part of geometry where the command is applied to. Moreover the user-gesture speed is taken into account to adjust the command: a slow and precise gesture will correct a local part of the topology while a fast gesture will correct a larger part of the topology. This allows to correct the anatomical aberrations or ambiguities that appear on the segmented model in a few strokes.

Keywords Sketching · 3D Reconstruction · Model Annotation

1 Introduction

Medical Imaging has been the major improvement in medicine over the last decades as it allows non-invasive accurate diagnoses of pathologies and diseases. The better the diagnosis, the more efficient is the medical procedure. To do so, acquisition devices such as MRI or CT scanners are able to provide high-resolution images of the human body that can be combined in order to build 3D models of anatomical structures (the reader may refer to [3] for a complete overview of 3D reconstruction techniques). However under some circumstances, theses techniques fail to provide a usable 3D model. For instance, within the interventional radiology context, the limited resolution of acquisition devices combined with small, thin, tortuous blood vessels make it very difficult to achieve an accurate reconstruction of the vascular network. Indeed artifacts such as holes, unwanted blending, very noisy surfaces are common on such reconstructed models (see figure 1). Usual and efficient solutions such as a combination of a statistical atlas [10] and non-rigid registration on medical images in order to avoid these artifacts are not convenient here since vascular networks exhibit high individual variability. In practice, experienced radiologists can interpret these 3D models and *mentally deduce* correct reconstructions. But they do not have the skills in 3D modeling, nor time, to refine the raw data and perform a valid 3D model, that would be understandable by interns or radiology beginners.

In this article we propose a sketch-based interface that would allow experienced radiologists to *annotate* models, so that beginners would more easily understand 3D reconstructions. In that context, annotating geometry means associating some part of the geometry to some predefined tag. Tags may be further used to exhibit semantic informations such as reconstruction errors, potential pathologies, non-consistent local topologies, or local topological informations (vessel segments, branchings identifications). The latter is a critical question about brain vascular system, because it extends the potential use of geometry annotation systems: such a functionality may significantly simplify and speed-up the task of defining the vessel network, and thus open the way to patient-specific simulation of catheter insertion.

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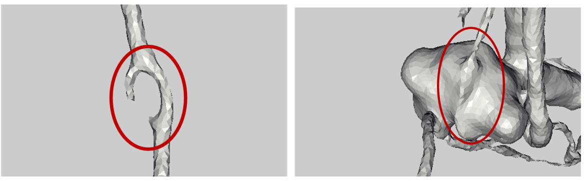

Fig. 1 Two examples of classical artifacts induced by automatic reconstruction: (left) topological aberration on a small artery, and (right) a small artery within an aneurysm (also known as a kissing vessel artifact).

The contribution of this article is a set of sketch-based commands (strokes), drawn on a multitouch device, that provide an intuitive way to structure existing 3D models of blood vessels. In this work we consider user strokes both as command that are to be recognized, *and*, anywhere relevant, a curve that has a meaningful position relatively to the reconstructed geometry. The main advantage of our approach is that each command also has context that can be used for selection of geometry, without having user to specifically select each triangle. Practically speaking, our contribution is to propose three following categories of strokes (detailed in section 3), aimed at topology edition of brain vascular systems. The algorithm employed for stroke recognition is very straightforward; however we introduce a original way to combine strokes and the way we use the stroke position to execute a command is novel.

2 Related Works

A lot of work study automatic reconstruction of surfaces from medical data but still requires human knowledge [9] or strong assumptions [4] on the structures to segment to produce a relevant and accurate 3D model.

Few works use an interface-based approach for 3D model topological reconstruction. [7] proposes a method for creating 3D models topology based on sketching (see [11,13] for a general introduction on using sketch for 3D modeling). sketch can also be used as a basis for the generation and control of realistic physically-based generation [18]: in such a work, both geometry and mechanical properties of hair is defined using sketch. [16] proposes a sketch-based approach that combines surface reconstruction with user dynamic feedback, through ad-hoc interface, on reconstruction errors. This approach takes advantage of volumetric field analysis, in order to adapt topology dynamically [5]. [15] proposes a specific method for automatic reconstruction of 3D models topology. [2] describes a method for automatically extracting topological structure for simple configurations. We refer the reader to [6] for a survey on sketch-based methods for topology modification of meshes. [17] describes how to extract skeleton curve from point cloud, possibly with large parts missing. [12] proposes a sketch-based interface for geometry deformation. [20] uses sketch-based interface for piecewise parameterization of meshes. Finally, let us also mention that sketch-based interfaces are also studied in the human computer-interaction field [8].

In the specific case of 1D structures, Pihuit & al [14] describe a system that interactively construct 3D models of vascular system by taking advantage of drawing conventions of medical community. [1] describes a method for interactive skeleton creation from intensity volumes. This approach efficiently extracts skeleton, from user input, and is also able to create branches. A lot of work has been achieved on the recognition of shapes for command. [19] recently described a nice and reasonnably well working method for curve classification.

3 Gestures

3.1 Linear Stroke

Our system presents two different ways to use linear strokes that only differs by their propagation on the mesh: *user-specified propagation* limits the topological element to the bounds of the user stroke, and *automatic propagation* propagates the topological vessel as much as possible, i.e. until bounds of reconstruction, or branchings connecting vessels together. We discriminate between the two sub-types of command using user gesture average speed, stating that accurate stroke is classically achieved slower than coarse ones. This empirical statement may need to be scientifically verified, but is very simple to implement, and appears to provide good results in our tests.

The two sub-types of propagation need a seed, a ring of triangles, to define a skeleton. All steps are defined in figure 2. After selecting the maximum dot product (A) between normals of picked triangles and camera direction to define a correct input point, a ring of points (C) is created around the axis define by gesture's direction and a centered point calculated with front/back picking (B) points from correct input point. Finnaly, to create initial seed (D), closest triangles are selected by comparing the distance between each point of the arbitrary ring (according to an arbitrary threshold). To create the skeleton, and to tag associated triangles, a stack algorithm recover next rings, to compose a skeleton, in two directions, interaction direction and the opposite, and estimate if propagation continue.The user-specified propagation is straightforward, as all user interaction points define the range of geometry that has to be structured. To stop automatic propagation, it's necessary to

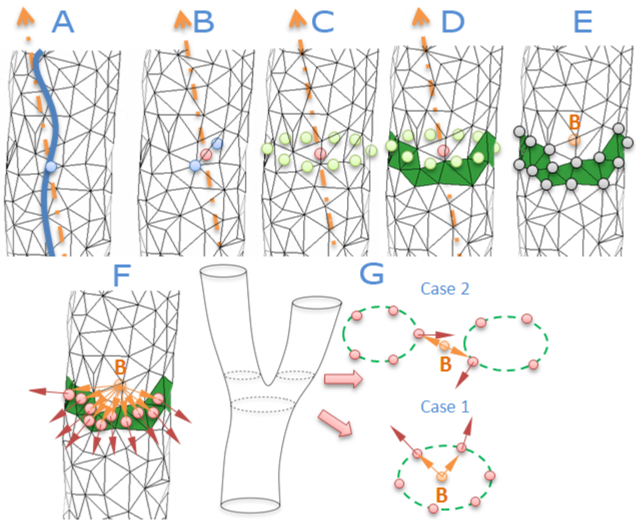

Fig. 2 Steps to set up the propagation seed and stop criterion: between two steps of the propagation, the algorithm can found two cases: the ring's average center is in the ring (below right) and average center is out (upper right).

define a geometry criterion to know if current ring isn't a junction.The geometry criterion is defined by, first, calculate barycenter (E) of the current ring using vertices of local mesh and secondly calculate vectors (F) start from this new barycenter to each ring's triangle center; then calculate one by one the scalar product of one vector and the associated normal, and made a mean of these scalar products to provide an evaluation of the geometric "opening" or "closing" (G) of the structure. The scalar product means and standard deviation, according with a basic thresholding technique help for decision of stopping propagation.

3.2 Circular Stroke

The association between a stroke and relevant triangles of the 3D-model is mandatory to ensure the topological reconnections of the local skeletons. With a circular stroke, the algorithm identifies with picked triangles under the gesture (see figure 3), the ones that are already tagged. Given the intricacy of brain veins and arteries and the possible inaccuracy of the user-gesture, control must be added to prevent the connection of distant (from a geodesic or topological point of view) skeleton parts. To do so, our strategy is to only connect skeleton parts where one of their extremities is enclosed by the circular gesture. This process is achieved using the parametric abscissa of each triangle. As each topological segment is a 3D curve and because each triangle is attached to a single skeleton part, we can compute the parametric abscissa of the projected triangle on the curve. Then topological segments are connected if and

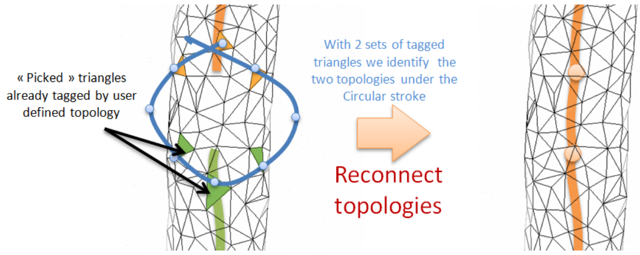

Fig. 3 Circular stroke encloses the extremities of the two topological elements (left), the reconnection is done leading to a single topological primitive (right).

only if they have some triangles picked AND the picked triangles have their parametric abscissa near to a arbitrary threshold to prevent connecting topological segments whose extremities may not be joined.

3.3 Walking Stick Stroke

The main issue raised with automatic reconstruction of medical images is the presence of unwanted blending that may merge two vessels or a vessel and an aneurysm (the so-called *kissing vessels* artifact). The purpose of the walking stick stroke is to handle this issue by selectively add local geometry to the reconstructed topology. The main idea is to sketch the wanted topology directly on the model. The gesture, which seems to be a stroke called *command* at the beginning, must start on already tagged part to extend the topology (see upper part of figure 4). The user needs to indicate via a break gesture, detected by a analysis of maximum curvature, the split direction of merged part called *parameter*.

Once the walking stick stroke has been characterized, the aim is to discriminate the merged parts (artifacts) on the model. As the gesture start on an already tagged part, some information like distance between skeleton an vessel surface or vessel direction are known. Considering that the surface-skeleton distance varies smoothly on merged structure, the algorithm can translate directly the command gesture as a skeleton by adding the beginning surface-skeleton distance and extend beginning skeleton in merged part. . The *parameter* curve allows to discard which part of the merged structure are identified by the user as non relevant. The figure 4 illustrates the walking stick stroke gesture on model with the initial step.

4 Test and Results

Some performance measurements were made (see Table 1) on different models in order to highlight the impact on the computation time of a linear stroke inter-

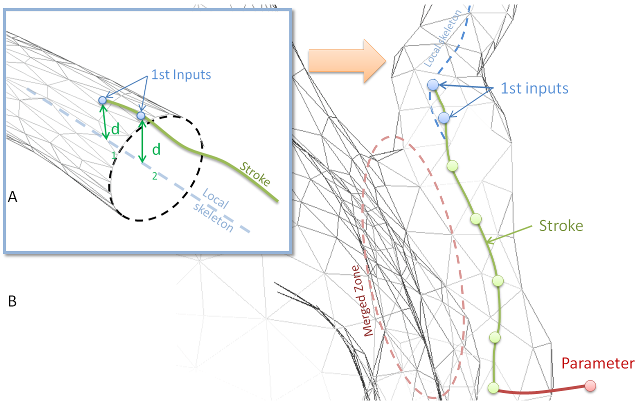

Fig. 4 Walking stick stroke: the user begins his gesture on a already tagged vessel (A), and continues his gesture by drawing the path of the kissing vessel (B). This action topologically disjoins the two merged structures.

Model Type: facets	Inputs	Treated	Time
Simple: 4384	7	3630	2386 ms
Y Topology: 3136	7	758	515 ms
Patient part: 8603	6	3955	1966 ms
Patient full: 45496	5	4926	2746 ms

Table 1 Measured performance on several test cases (full propagation).

action with an automatic propagation. These measurements was made on HP Z400 Workstation: 4.0Go RAM, Quad-Core Intel XEON W3520 at 2.66Ghz and NVidia Quadro FX580 for graphics rendering. The models tested are: a simple tubular model (with a large section), a model Y generated (ordered mesh), a local part of a patient brain vascular network, and the full vascular network.This is the most consuming time part of the algorithm and varies almost linearly with respect to the number of triangles.

5 Conclusion and Future Work

The paper presents three different gestures that allow to define the topology of a vascular network. The main originality of our approach is to handle the user gesture as both a command and data to apply the command. Future works will focus on the validation of the three strokes as some arbitrary threshold have been set. Moreover, a clinical validation is required in order to asses the relevance of our method compared to the clinicians needs. As a consequence, additional features may be derived from this topology definition such as local geometry reconstruction and / or modification.

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